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EVALUATION OF CONCRETE CORES FROM THE DSS 14 ANTENNA SUPPORT STRUCTURE GOLDSTONE, CALIFORNIA

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by

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EVALUATION OF CONCRETE CORES FROM THE DSS 14 ANTENNA SUPPORT STRUCTURE GOLDSTONE, CALIFORNIA

Final Report

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INTRODUCTION

Under JPL Contract No. 956494, Modification 5, Construction Technology Laboratories (CTL) is monitoring the static modulus of elasticity of concrete cores taken from DSS 14 antenna support structure located at Goldstone, California. The purpose of this study is to determine whether alkali-silica reactivity, previously diagnosed as a cause of degradation of pedestal concrete, is continuing to cause deterioration under a range of moisture and temperature conditions known or considered to be present in the structure.

Testing was initiated in February, 1985 and was carried out for a period of 26 months. This final report includes data obtained to characterize the condition of the concrete during this period of testing. Details and results of the study are given below.

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NATURE OF THE PROBLEM

In previous work conducted by CTL and others, alkali-silica reactivity was identified as a major cause of cracking and degradation of concrete in the DSS 14 antenna support structure. In this type of reactivity, three requirements must be met for expansion to occur. These requirements are:

1. Sufficient alkali.
2. Reactive forms of silica or silicate material in the aggregate.
3. Sufficient moisture.

In simplified terms, the reaction can be viewed as a two-step process. First, alkalies (Na and K) in solution in the concrete react with the silica or silicate aggregate to produce a gel reaction product. At this point no expansion or cracking occurs. In the second step, the gel reaction product imbibes moisture and swells, thereby generating pressures that can exceed the tensile strength of the concrete and cause cracking.

Commonly, low alkali cement (less than 0.60% as equivalent Na_2O) will inhibit expansive reactivity. However, where reactive feldspathic rock types are present, low cement alkali levels may not be a sufficient safeguard.

In the antenna support concrete, low alkali cement was reported to have been used. However, both the fine and coarse aggregate contained reactive glassy to cryptocrystalline volcanic (feldspathic) material of rhyolitic to andesitic composition, together with minor chert. These rock types were found to have reacted in the pedestal concrete.

As noted above, sufficient moisture is required to be available to the gel reaction product for expansion to occur. In earlier work under this contract to evaluate effects of moisture, laboratory tests indicated that expansion could occur if the relative humidity (RH) of the concrete exceeded 80 to 85%, referenced to 70 to 75°F. Field measurements indicated that the RH of the pedestal concrete ranged from about 40 to 85%, depending on proximity to exposed (coated or painted) concrete surfaces. The lower RH values were measured near exposed surfaces, thus indicating an overall drying trend in the concrete. It is significant that interior RH values in wall concrete reached a maximum of about 80 to 85%, which is the threshold to support expansion. Thus, essentially all of the pedestal concrete above grade was considered to be sufficiently dry to preclude further expansion due to reactivity.

As a precaution, it was recommended that concrete cores from the pedestal be included in an extended monitoring program to confirm that deleterious alkali-silica reactivity is not continuing in the wall structure. Equally important, no data were available on concrete from the pedestal footing located below grade. At these depths, it was reasoned that soil moisture could diffuse into the concrete, thereby maintaining a moisture condition sufficient to permit expansive reactivity to occur.

Accordingly, both wall cores and footing cores were included in the test program to monitor the course of possible alkali-silica reactivity in concrete stored under temperature and moisture conditions covering the range considered to exist in the antenna support structure.

TEST PROCEDURES

In view of the importance of concrete stiffness in antenna operations, static modulus of elasticity was utilized as the parameter to monitor the effects of possible alkali-silica reactivity. Static modulus is considered to be sensitive to the effects of alkali-silica reactivity since modulus of the concrete depends to a large extent on modulus of the aggregate, the strength of paste-aggregate bond, and the presence of microcracking. Expansive reactivity affects all of these factors.

Four test exposure conditions were selected for this program. These conditions, together with the rationale for their selection, are given in Table 1. As will be noted, these exposures include those either favorable or not conducive to expansive reactivity, as well as those previously identified or estimated to exist in the pedestal concrete.

Twenty-eight concrete cores, nominally 3-3/4 in. in diameter and 7-1/2 in. long, were prepared for testing. This group included 22 wall cores and 6 footing cores. Six of the 22 wall cores are duplicates of other wall cores taken at the same location. Table 2 lists the locations from which the

TABLE 1 - TEST EXPOSURE CONDITIONS IN CORE MONITORING PROGRAM

Temperature °F	Relative Humidity-%	Means of Storage	Rationale
100	100	Cores stored over water in sealed container located in 100°F room.	Condition favorable to expansive reactivity. Leaching of alkali from concrete minimized. Standard condition for ASTM tests.
73	100	Cores stored over water in sealed container located in 73°F room.	Moisture condition favorable to expansive reactivity. Leaching of alkali minimized. Temperature estimated to be in range of that encountered in wall and footing concrete. Reaction should be slower than at 100°F.
73	80	Cores stored over saturated $(NH_4)_2SO_4$ solution in sealed container located in 73°F room.	Moisture condition close to maximum level measured in wall concrete and therefore represents approximate conditions in wall most favorable to reactivity. RH also is close to minimum required to permit expansive reactivity. Temperature in range close to estimated average in wall and footing.
73	50	Cores stored in room maintained at 73°F and 50% RH.	Represents conditions sufficiently dry to preclude expansive reactivity, and approximately lowest RH measured in wall.

TABLE 2 - LOCATIONS OF CORES INCLUDED IN MONITORING PROGRAM

Core Design-tion	Location in Structure	Depth of Core from Exposed Surface, in.	Test Condition
2C	Wall core, true A_z-northeast	22 to 29-1/2	100°F 100%RH
4C	Wall core, true A_z-southeast	20-1/2 to 28	
6B	Wall core, true A_z-southwest	13-1/2 to 21	
8C	Wall core, true A_z-northwest	20 to 27-1/2	
F4(4)	Footing core, true A_z-northeast	19 to 26-1/2	
F8(4)	Footing core, true A_z-northwest	3 to 10-1/2	
1C	Wall core, true A_z-north	16-1/2 to 24	73°F 100%RH
3B	Wall core, true A_z-east	13-1/2 to 21	
4A	Wall core, true A_z-southeast	5-1/2 to 13	
5C	Wall core, true A_z-south	21 to 28-1/2	
7C	Wall core, true A_z-west	21 to 28-1/2	
8A	Wall core, true A_z-northwest	5 to 12-1/2	
F4(2)	Footing core, true A_z to southeast	19 to 26-1/2	
F8(2)	Footing core, true A_z-northwest	3 to 10-1/2	
1B	Wall core, true A_z-north	9 to 16-1/2	73°F 80%RH
2B	Wall core, true A_z-northeast	13 to 20-1/2	
4B	Wall core, true A_z-southeast	13 to 20-1/2	
5B	Wall core, true A_z-south	13-1/2 to 21	
7B	Wall core, true A_z-west	13-1/2 to 21	
8B	Wall core, true A_z-northwest	12-1/2 to 20	
1A	Wall core, true A_z-north	1-1/2 to 9	73°F 50%RH
2A	Wall core, true A_z-northeast	2-1/2 to 10	
3A	Wall core, true A_z-east	6 to 13-1/2	
5A	Wall core, true A_z-south	6 to 13-1/2	
6A	Wall core, true A_z-southwest	6 to 13-1/2	
7A	Wall core, true A_z-west	6 to 13-1/2	
F5(4)	Footing core, true A_z-south	14-1/2 to 22	
F8(3)	Footing core, true A_z-northwest	3 to 10-1/2	

A_z indicates azimuth.

individual cores were obtained, together with their respective depths from exposed concrete surfaces. Core selection for each exposure condition was based on location in the structure. One core from each of four groups was placed in each exposure. Core Nos. 1 and 2 were considered as one group from the same location; Nos. 3 and 4 were considered as another group; Nos. 5 and 6 and Nos. 7 and 8 were considered as two additional groups.

Depth of core section also was considered in the assignment of cores to the test environments. Thus, a majority of wall cores from near exposed surfaces were placed in the 73°F, 50% RH environment to more closely simulate measured conditions in the wall of the support structure. Deeper cores were stored at higher RH levels to more closely approximate moisture conditions near mid-depth in the wall. Footing cores were placed in three test conditions. Two of these were 100% RH environments to simulate presumed damp conditions due to diffusion of moisture into concrete from adjacent soil. The third set of cores was placed in the 73°F, 50% RH environment to serve as a reference condition under which expansive reactivity should not occur.

Except for environmental conditioning, all testing was conducted in accordance with ASTM C 469-83, Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression. Core preparation consisted of sawing sections to the required 7-1/2-in. length, then capping to provide smooth parallel surfaces to insure uniform loading. For several footing cores, 7-1/2-in.-long intact sections could not be obtained. Therefore 1/2-to 1-in.-thick sections of footing concrete were glued to each end of these cores to provide the required distance between the compressometer and the end surfaces of the cores.

At the time modulus of elasticity measurements were made, each core was removed from its respective exposure condition, wrapped in plastic sheeting to prevent moisture exchange with the test environment, and fitted into the compressometer. Each successive measurement on a core was done with the compressometer in the same position. Prior to measurement at each age, the compressometer was recalibrated using an aluminum cylinder of known modulus.

In addition to modulus of elasticity measurements, each core section was weighed after capping and storage in laboratory air for several weeks, but before conditioning, then weighed several times before the first modulus measurements were made. Additional weighings were made each time modulus measurements were obtained. This was done to identify possible influence of moisture gradients on results of modulus measurements.

TEST RESULTS

Results of all modulus of elasticity measurements are given in Table 3. Average weight changes due to loss or gain of moisture are shown in Fig. 1. Figure 2 illustrates the trends in modulus values for wall cores, while Figure 3 shows the trends for the footing cores. Three load cycles were placed on each core at each age to determine modulus. An example of the

TABLE 3 - RESULTS OF MODULUS OF ELASTICITY MEASUREMENTS

ON CONCRETE CORES FROM DSS-14 PEDESTAL CONCRETE

Core No.	Exposure Condition	Modulus of Elasticity(ksi) Test Age-Days 55	146	238	418	619	780
2C	100°+100%	4100	4500	4700	4600	5000	5100
4C		3400	3600	3700	3800	4300	4400
6B		3200	3300	3600	3500	3900	4200
8C		2900	3400	3400	3500	3600	3600
F4(4)		4400	4500	5200	4800	5400	5000
F8(4)		3500	3900	4300	4100	4300	4700
1C	73°+100%	3000	3100	3500	3600	4200	4500
3B		3100	3400	3500	3500	4200	4300
4A(Dup)		2400	2500	2800	2800	3500	3700
5C		3400	3700	4400	4400	4800	4800
7C		3500	3700	3600	3900	5500	4400
8A(Dup)		3100	3300	3600	3700	4300	4400
F4(2)		2700	3000	2800	3200	3700	3800
F8(2)		3800	4300	4700	4300	4700	4800
1B(Dup)	73°+80%	3500	3700	3900	●	*	*
2B		3900	4500	4500	4100	4500	4200
4B		3600	4000	4100	3700	4100	●
5B		2100	2400	2400	2500	2400	*
7B(Dup)		4000	3900	4500	4400	4600	4300
8B		3100	3300	3400	3200	3400	3400
1A	73°+50%	2800	2900	3100	3100	2900	3000
2A(Dup)		3500	3600	3800	3400	3500	3700
3A		2800	2900	3100	3000	2900	2900
5A		3500	3800	3800	3800	3800	3600
6A(Dup)		2800	2800	2900	3000	2500	3000
7A		3000	3000	3400	3000	3200	3100
F5(4)		3200	3400	3500	3100	3400	3200
F8(3)		3000	3000	3500	3200	3200	3400

All data are averages determined from 2nd and 3rd load cycles at each age.
"Dup." indicates duplicate core in a group from the same location.

*Testing discontinued due to accidental partial immersion of specimens in $(NH_4)_2SO_4$ solution, resulting from corrosion of support rack.

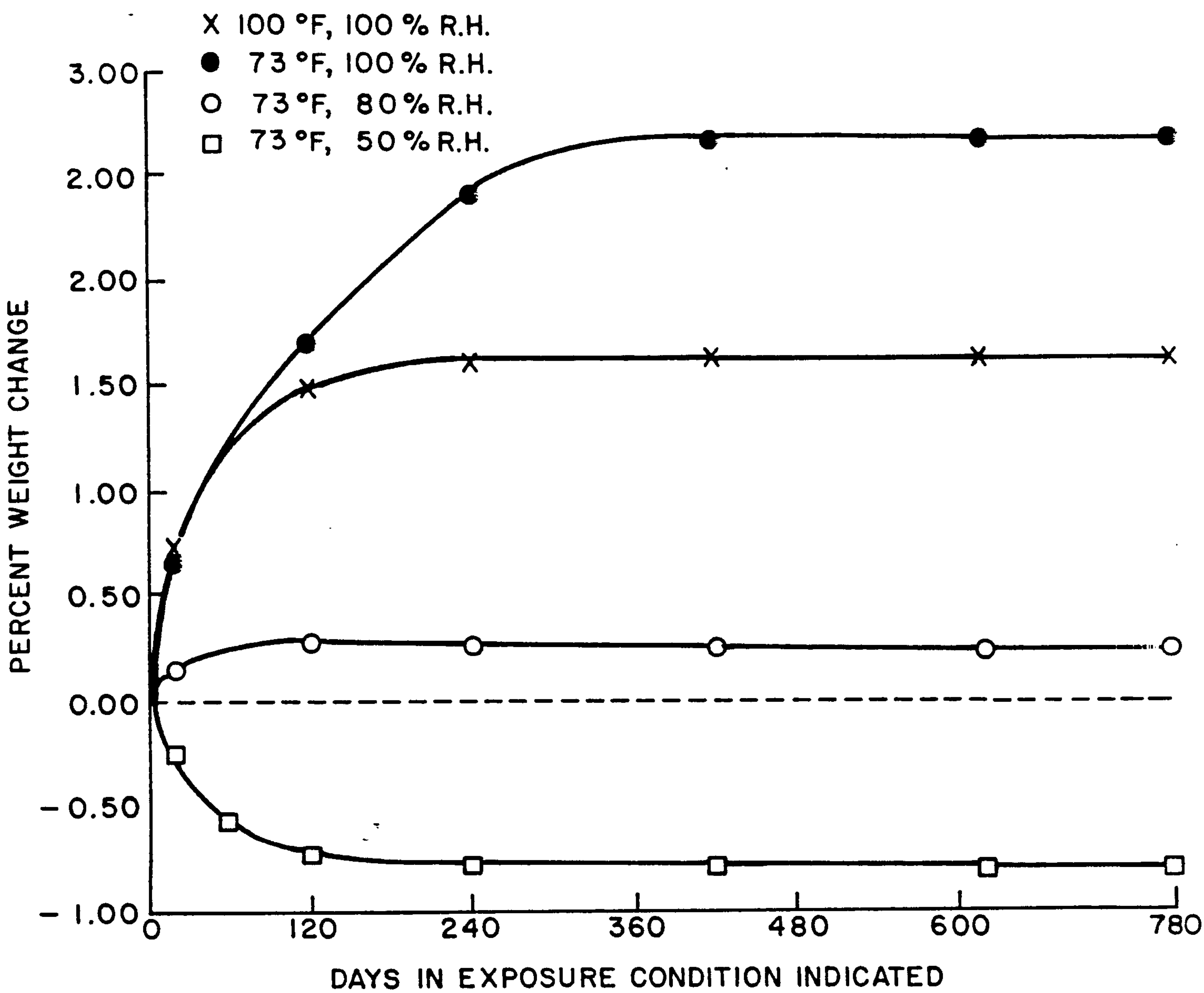

FIG. I - AVERAGE WEIGHT CHANGE DUE TO GAIN OR LOSS OF MOISTURE IN CONCRETE CORES FROM DSS 14 PEDESTAL

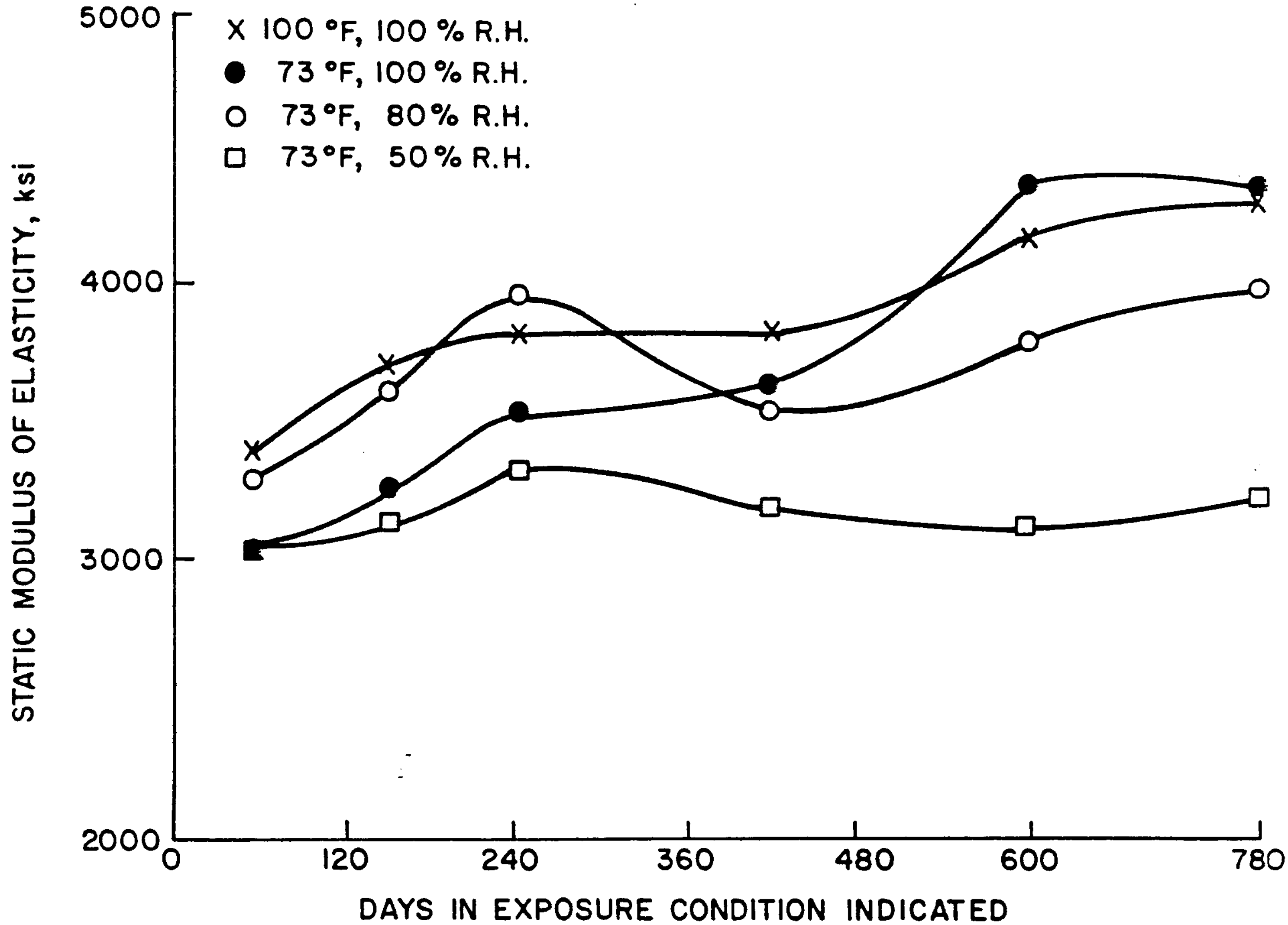

FIG. 2 - AVERAGE STATIC MODULUS OF ELASTICITY OF CONCRETE CORES FROM WALL OF DSS 14 PEDESTAL

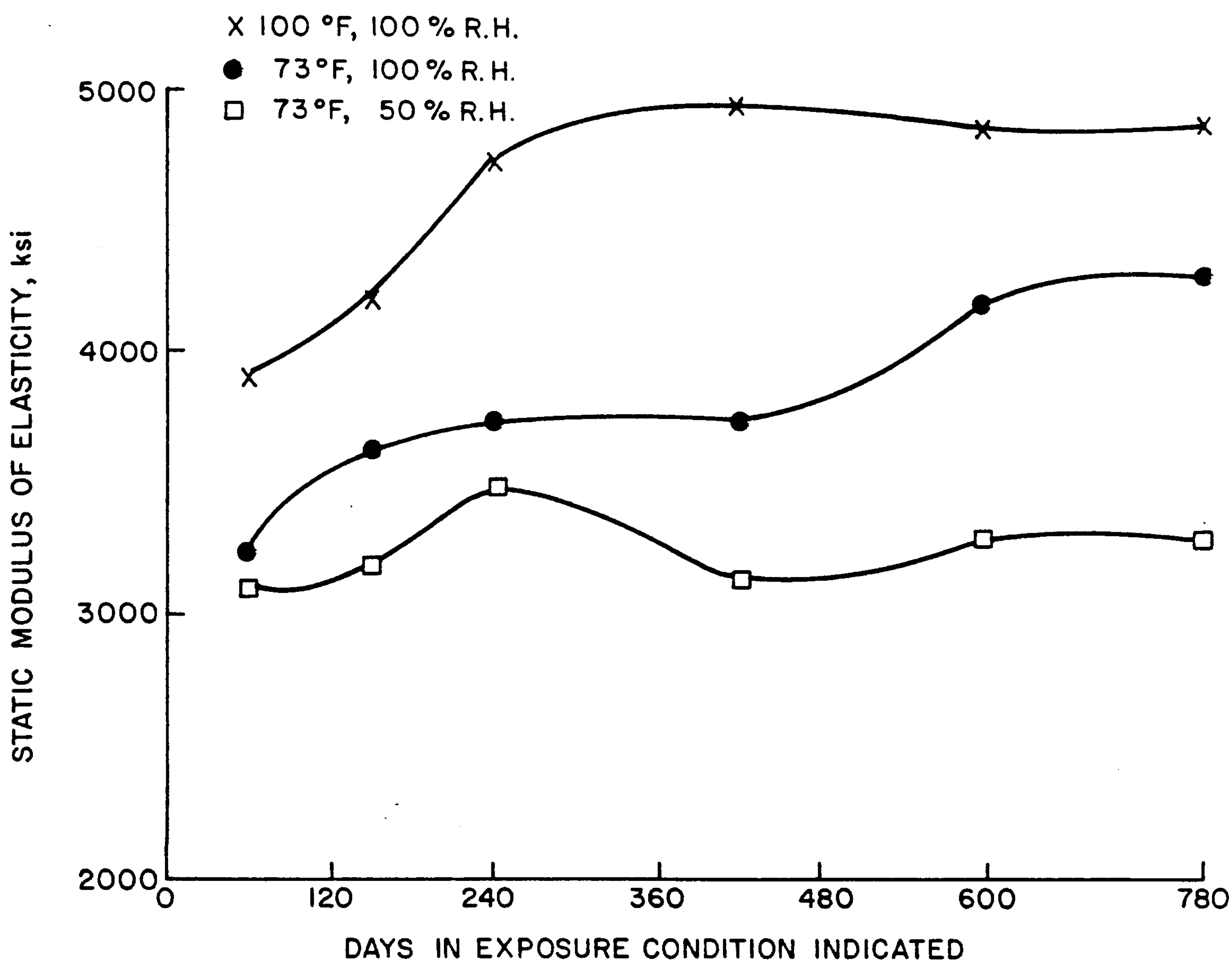

FIG. 3 - AVERAGE STATIC MODULUS OF ELASTICITY OF CONCRETE CORES FROM FOOTING OF DSS 14 PEDESTAL

measured stress-strain characteristics for Core 4A is shown in Fig. 4. Primary features of these data are the hysteresis and the curved shape of the stress-strain relationship at low stresses. These features are typical of data from deteriorated concrete. Data from the second and third cycles were averaged to provide the moduli results given in Table 3.

Results of weight change measurements shown in Fig. 1 indicate that approximate moisture equilibrium was reached after about 120 days for cores stored at 50% and 80% RH at 73°F, and for cores stored at 100% RH at 100% F. Close to one year was required for cores to reach moisture equilibrium at 100% RH and 73°F. Core weights indicate that moisture contents remained essentially constant thereafter.

Results of modulus of elasticity (Mod E) measurements after 780 days of testing are summarized in Table 3 and Figs. 2 and 3. These data do not indicate progressive degradation of the wall and footing cores under the storage conditions used in this test program. That is, expansive alkali-silica reactivity did not produce further distress in the test specimens at either 73°F or 100°F, and 50%, 80%, or 100% RH. If deleterious reactivity had occurred, it would be expected that Mod E values would decrease. No significant reduction in Mod E values was expected for cores stored at 80% and 50% RH conditions. At 100% RH, the concrete would be sufficiently damp to permit expansion and cracking due to uptake of moisture by alkali-silica gel reaction products. At 80% RH and 50% RH, the concrete would be too dry, after moisture equilibrium (stable

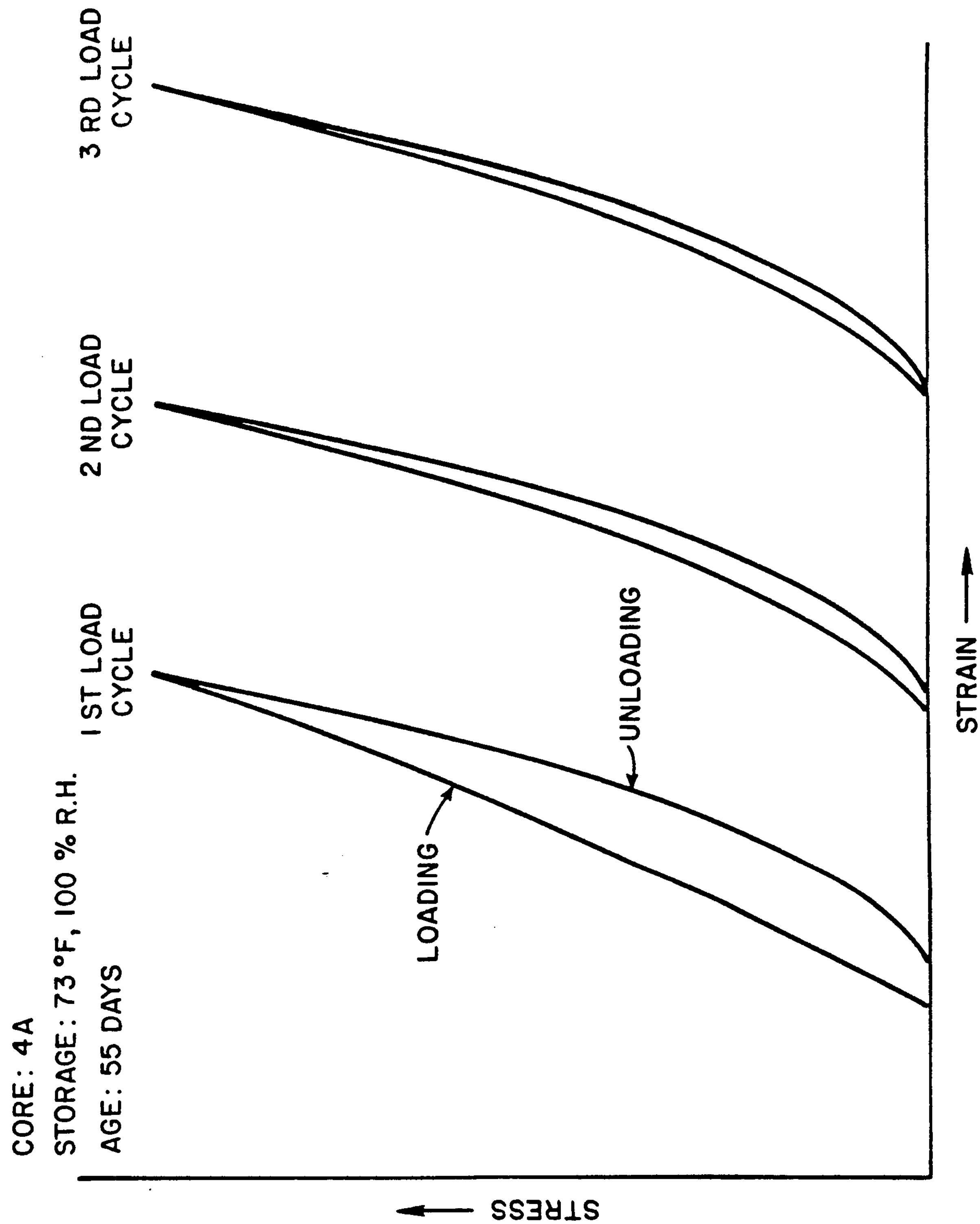

FIG. 4 - HYSTERESIS EFFECT IN STRESS - STRAIN CURVE

weight) is reached, for moisture to be absorbed by gel reaction products.

In contrast, Mod E values show general overall increases at 100% RH and 80% RH for both the wall cores and footing cores. Since absorbed moisture is a load-bearing component of concrete, the increase in measured Mod E values appears to be due primarily to the increase in moisture content of the concrete. To a minor extent the increases in Mod E values may also be due to redistribution of <u>preexisting</u> alkali-silica gel in microcracks formed before the concrete was tested. In any case, the data indicate no deleterious alkali-silica reactivity.

SUMMARY AND CONCLUSIONS

It has been established by previous investigations that deleterious alkali-silica reactivity has occurred in the Goldstone, California DSS 14 antenna support structure. This was established by the combined results of petrographic examinations, measured low modulus of elasticity values, and by characteristics of the stress-strain curves used to determine modulus values.

Monitoring of modulus of elasticity data over time, for wall and footing core specimens under specific test storage conditions, thus far indicates that further deleterious alkali-silica reactivity is not occurring. This is evidenced by overall trends in the data which suggest modest increases in moduli in the 100% RH environments which would be particularly favorable to expansive reactivity. Cores stored at lower RH environments showed relatively stable moduli between 240 and 780 days. Thus, it appears that expansive alkali-silica reactivity has essentially exhausted itself in wall and footing concrete.